PB-215 102

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Public Health Service
Cincinnati, Ohio

1938

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STREAM POLLUTION AND ITS CONSEQUENCES.*

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The pollution of our streams and public waters has been so widely discussed and so generally abhorred that it is no longer necessary to describe in detail the train of damaging effects that result from such nuisance, in order to arouse interest in this subject and stimulate the institution of corrective measures. It is of importance, however, that we who are responsible for the protection of the public health through the provision of safe water for drinking, household and recreational uses should comprehend the chain of reactions which occurs when these waters either in the raw or treated state, are subject to undue pollution. This leads us to a consideration, not only of the problems relating to the production of safe drinking water but to those in the related fields of stream pollution and natural purification of sewage and industrial waste treatment.

The Uses of Streams.

It is generally acknowledged that the primary and highest use of water is for human consumption and that any other uses are of secondary importance. Such additional uses may be: (a) for the production of food, watering of stock, irrigation of farm land or growth of fish, (b) disposal of liquid sewage wastes of both domestic and industrial origin, (c) recreation, including swimming,

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(*) Prepared for presentation at Texas Water Works School Short Course, February, 1938.

boating and bathing, and (d) navigation and water transport. The relative values of these secondary uses will vary with each particular stream, depending upon local conditions. In most instances, a single stream renders more than one of these services and in such cases, the degree importance of these different functions must be carefully evaluated in the development of an economically sound pollution control program.

Nature and effect of pollution.

Polluting substances as commonly found in streams originate from one of three principal sources, human or animal populations; industrial development; or natural agencies such as soil erosion, leaching out of soluble salts or materials and products of vegetable growth or decay. This wide range of polluting materials may be placed in various classifications or groupings. One of the broadest is perhaps that of organic and inorganic substances. Organic substances embrace a wide variety of complex compounds containing carbon many of which readily decompose in water through bacterial action and have an avidity for oxygen in the process. Inorganic or mineral substances usually are more stable and are frequently directly detrimental. A somewhat different classification pertains to the effects they produce as (1) toxic or harmful stable chemicals such as poisons, acids, alkalis, oils, dyes and similar materials which exert a direct detrimental effect upon animal or plant life, (2) inert substances such as clay, sawdust, wood pulp and carbon which, while not in themselves injurious, yet by their presence create objectionable conditions and interfere with the normal uses of the waters in which they are placed, and (3)

organic matter, including sewage and numerous industrial wastes which, on decomposing, reduce the dissolved oxygen content of the water and frequently contain pathogenic organisms.

Of these three general classes of polluting matters the chemicals are perhaps the most varied in composition and very frequently the most difficult to treat effectively. Many of them exert direct, detrimental effects upon the public health, where the waters into which they are discharged are used for drinking water supplies. Quite often such chemicals are difficult to remove once they reach natural streams, and for this reason it is generally advisable to treat or dispose of such waste liquors before they are discharged to watercourses. Even where the offending chemicals are harmless in themselves, they may create such objectionable tastes or odors in the water that consumers are driven to unsafe private sources of drinking water. Such pollution is thereby indirectly detrimental to the public health. Donaldson (1922) stresses this indirect effect and cites several examples where consumers have been driven to unsafe private supplies, including one instance where salt wastes from oil well operation in the public supply were the cause of a typhoid outbreak among consumers of a less objectionable but contaminated private supply.

Among the more well known harmful chemicals appearing naturally in surface waters are salt brines, fluorides, sulphur compounds and selenium salts. Others artificially produced include the directly objectionable chemical wastes resulting from lead and coal mining, oil wells, plating and galvanizing, copper and zinc

refining and a large variety of chemical industries discharging acids, alkalis, dyes or toxic chemicals. Donaldson (1921) in discussing the relation of industrial wastes to water supplies, classifies the unfavorable effects generally manifested as: (a) disagreeable odors and tastes, (b) unsightly appearance or interference with proper functioning of treatment processes and (c) chemical substances in solution which, though not objectionable to sight or taste, may cause actual damage to water works structures, render the water less fit for domestic or industrial use on account of hardness or other chemical properties and may or may not be detrimental to health. The waste chemicals thus discharged to streams, in addition to their effect on health when in sufficient concentration, are injurious to live stock, vegetation and aquatic life. The result is depreciation of riparian property used for agricultural, residential and many industrial purposes, damage or destruction of fish, and interference with normal natural purification processes through destruction of the minute biological life of the water. Quite frequently such damage is more costly and more insistently emphasized than that affecting the public health.

Much work has been done to determine the toxic effect upon various species of fish of numerous industrial wastes in different concentrations. Such information is generally available and of real value in estimating limiting permissible discharge of such wastes into streams of known volume of flow. A summary of such data has been made by the Bureau of Fisheries, U. S. Department of Commerce, as well as by several state bureaus concerned

with these matters. The very minute amounts of certain waste chemicals required to poison such game fish as trout, pike, etc., points to the necessity of care in the disposal of chemical effluents in the interest of preserving fish life.

Another harmful effect of chemical waste effluents is the interference with biological purification processes of sewage treatment and of natural stream purification. These processes are dependent for their proper functioning upon the activity of minute and sensitive organisms which inhabit the polluted liquids in immense numbers and which have the power of breaking down complex organic matter into simple forms. They are adversely affected by many chemicals and their work is thereby interrupted or halted with disastrous effects to the purification process. Thus, Scoullar (1926) found that acid salts of iron and aluminum inhibit or retard the purifying action of activated sludge and cause it to contract in volume. Cameron (1930) reports exceptionally trying experiences in the operation of the Fostoria, Ohio, sewage treatment plant resulting from excessive amounts of finely divided carbon, ferrous sulphate, sulphuric acid, oils and greases contributed by large manufacturing plants to the city's sewerage system. Extensive repairs were necessary to rehabilitate the plant after these wastes were excluded, and numerous damage suits were brought against the city by riparian owners below the sewage works for failure to properly treat the sewage. Gas works liquors and wastes from coal distillation are another class that cause widespread troubles in sewage treatment works as recorded by numerous writers, including Key (1932), Slater (1932), O'Shaughnessy (1931),

Mohlman (1929), and Hooper (1928).

Pollution of streams by inert substances that contribute no harmful ingredients to the waters in which they are placed is perhaps more extensive than pollution by chemicals or organic matter. The most widespread pollution of this nature is that contributed by surface wash whereby large volumes of soil and clay are added to the streams as a result of heavy precipitation which, however, is not of direct industrial origin. The amount of clay carried by our rivers is not generally appreciated. Thus the Ohio River at Cincinnati, with a watershed of 71,000 square miles, during the period 1914-16, carried a total of over 14 million tons of turbidity per year or about 200 tons per square mile of drainage area. This pollution is, of course, not preventable. There are other kinds of inert materials that can be largely eliminated from our streams, particularly wastes from wood and paper pulp industries. Generally recovery of wood fiber from paper mill waste is not particularly difficult and is frequently profitable.

The most varied and extensive class of polluting substances are those of an organic nature, resulting from a very great number of industrial processes and from the contribution of sewage from our cities and towns. These organic compounds are unstable, that is, they are broken down more or less rapidly by bacteria in the receiving stream, require appreciable amounts of oxygen in the process if it is available, and if it is not, create conditions of nuisance such as objectionable odors, discoloration of the water, development of unsightly organic growths, deposits of decomposing sludge, etc. Furthermore, such wastes and sewage

frequently carry harmful pathogenic bacteria capable of spreading disease if taken into the human system. It is this type of pollution which is of universal concern to the public health officials charged with the protection of public water supplies and maintenance of standards of stream sanitation.

The process of self-purification.

Streams and other bodies of water have a definite capacity for assimilating organic pollution without nuisance. The disposal of sewage and wastes by dilution is a perfectly practicable procedure and one that is widely used. It is only when excessive loads of pollution are imposed that this process fails and objectionable conditions result. It is of interest, therefore, to ascertain the forces operative in this self-purification activity, to learn of their limitations and especially to discover methods by which they may be reinforced or stimulated. The Public Health Service, through its organization of Stream Pollution Investigations, has been interested in research studies of this nature over a considerable period of years.

The natural purification of organic polluting material in streams is dependent upon the action of bacteria and plankton present in the water. When these biochemical changes occur in the presence of oxygen dissolved in the water, they are generally designated as aerobic but if they proceed in the absence of oxygen they are called anaerobic. Aerobic decomposition processes are comparatively rapid, direct and inoffensive and result in the formation of stable mineral compounds. Anaerobic decomposition results in some stable mineral forms and in addition other mineral products of

objectionable qualities such as methane and hydrogen sulphide which contain no oxygen. In stream purification it is desirable to maintain aerobic conditions throughout the process to avoid the objectionable conditions induced by anaerobic fermentation; that is, sufficient dissolved oxygen should be present at all times to supply the requirements of the aerobic organisms.

A wide variety of bacteria in water use the organic matter for food, breaking down the complex compounds in the process and converting them into stable forms when an excess of dissolved oxygen is present. The course of these fermentative changes occurring in the organic matter proceeds in two distinct stages, the first of which merges into the second. This reaction proceeds in accordance with a definite law which, as enunciated by Adeney (1932) states: "The quantities of oxygen consumed and of products formed on the completion of each stage of aerobic fermentation are constant for similar volumes of the same polluted water. This law is applicable to all polluted waters, tidal and nontidal, undergoing purification by bacteria fermentation, provided that the dissolved oxygen be in excess of the fermenting matters." This constant relation between dissolved oxygen consumed and oxidizable organic matter gives us at once a method of measurement of organic pollution, the familiar biochemical oxygen demand test.

In this first stage of natural purification the complex carbonaceous and nitrogenous compounds are changed to simpler forms. The carbon compounds are oxidized chiefly to carbon dioxide and water, together with small amounts of organic products or humus, while the nitrogen containing constituents are reduced with the pro-

duction of ammonia. During the second or nitrification stage of fermentation the ammonia and humus are further oxidized to nitrates and carbonates. Anaerobic decomposition takes place only during the first stage and then only when the dissolved oxygen has been exhausted; it never recurs in the second step of the fermentation process. The motivating power in both these stages is the bacteria.

Extended observations indicate that these bacteria are most active, if not entirely so, during the time of their multiplication. When no agencies are present to interfere with their normal reproduction, multiplication of bacterial numbers will proceed to a definite maximum or ceiling depending upon the concentration of available food material - that is - organic pollution. During this multiplication stage available dissolved oxygen is used up but when the upper limit of bacterial concentration is reached, further activity practically ceases and little further oxygen is required. If now some natural enemy is introduced that reduces the bacterial concentration, such as bacteria-eating plankton, further multiplication is stimulated to maintain the upper limiting number and oxidation of the organic matter again proceeds to completion. It would appear then that at least one of the functions of the large group of animal plankton in polluted water is to control the biological balance and stimulate the development of bacterial cells which in turn is necessary for the natural course of oxidation of organic matter. These plankton, therefore, have just as essential a role in the natural purification process as have the bacteria or the dissolved oxygen.

These bacteria and plankton are normally present in polluted water, and their functioning is therefore more or less a matter of course under favorable environmental conditions. The sufficient supply of dissolved oxygen required for their oxidation work is, however, a vital problem and is the factor that usually limits the speed of natural purification in polluted streams. When this oxygen supply is deficient, objectionable putrefactive conditions result. This reserve dissolved oxygen supply is never large because the capacity of water for the solution of oxygen ranges from approximately 14 milligrams per liter at just above freezing to about 7.6 milligrams per liter at 30°C., or in other terms, from about 0.81 grains to 0.44 grains of oxygen by weight per gallon of water. Unless this dissolved oxygen supply is continuously replenished, therefore, the biochemical oxidation is retarded. Nature provides this replenishment under well defined laws, through the process of reaeration. Hence the rate of reaeration is another limiting factor in the natural purification process.

These two opposing reactions, deoxygenation induced by bacterial action and reaeration operating to transfer atmospheric oxygen into solution in the deaerated water, tend always to come to a condition of equilibrium. If the polluted water is nearly saturated with oxygen, there is a rapid rate of withdrawal of oxygen by bacterial action and a slow rate of replenishment from the atmosphere. Since the rate of reaeration is directly proportional to the existing saturation deficit, the rate of reoxygenation is increased as the dissolved oxygen decreases until the rate of depletion equals the rate of reaeration. At this time the two re-

actions are for the moment equal and there is no change in the actual dissolved oxygen content. If now the decreasing oxygen demand of the organic matter, resulting from its own oxidation, reduces the rate of withdrawal below the rate of reaeration, the dissolved oxygen will be gradually replaced until the water is again saturated with oxygen. If, on the other hand, the pollution is so intense that the rate of withdrawal of oxygen is continuously greater than the maximum rate of reaeration can supply, a condition of complete deoxygenation will result and anaerobic fermentation will ensue, until such time as the reaeration rate can exceed the withdrawal rate. In the efficient functioning of natural purification processes it is, therefore, important not to exceed the assimilating capacity of the stream for organic waste under aerobic conditions, as it is only when such overloading occurs that objectionable nuisance conditions result.

Another phase of the natural purification phenomenon is the extent and rate of disappearance of bacteria in polluted streams, including both the harmless forms and pathogens. The extent of decrease in water is the resultant of various factors to which bacterial cells are extremely sensitive including readily available food and oxygen supply, environmental conditions such as temperature, light and hydrogen ion concentration and predatory enemies principally bacteria eating plankton. Age of cells alone is of doubtful importance as a reducing agency. Extended observations of the rates of bacterial decrease below sources of organic pollution in such larger streams as the Ohio, Illinois and upper Mississippi River supply definite information on this subject.

These rates are usually orderly, consistent and, within limits, quite uniform under similar conditions. They are higher in summer than in winter, are apparently modified by the original concentration of bacterial pollution, and are disturbed by sudden changes in conditions of flow such as heavy run-off from rains. Further experimental data indicate that the rates of decrease are much more rapid in smaller trickling streams than in larger slow-moving rivers.

Artificial measures for improving stream sanitation.

It is frequently necessary to resort to artificial measures to reinforce the natural purification rates and prevent overburdening of polluted streams. Such measures may be directed toward the stream itself through facilitating reaeration and oxidation or removal of organic material, or more directly toward the polluting wastes by means of various methods of treatment. Natural purification of streams may be encouraged in a number of ways. Means may be provided for the precipitation of suspended material through the storage facilities of reservoirs and reaeration by extensive surface exposure as is now being practiced in the Ruhr River in Germany, agitation or turbulence of the flowing water may be induced to speed up the rate of reaeration, oxygen-bearing chemicals may be added to furnish an additional source of available oxygen, or biochemical oxidation may be temporarily delayed by disinfecting chemicals such as chlorine.

The beneficial effect of storage in aiding natural purification is well exemplified in the Ohio River, now completely

canalized during low water flows. The pools thus formed greatly extend the time of flow between points of major pollution such as Cincinnati and Louisville, and as a result, during pool stages, longer periods are provided for the operation of natural purification processes. During such times, little observable effect of the pollution contributed by the Cincinnati metropolitan district with a population of over 600,000 can be detected at Louisville, 140 miles below. However, during periods of high water when the channel is unobstructed by navigation dams, the pollution contributed by Cincinnati is readily determined in the section of river above Louisville.

Methods of artificial treatment of sewage and organic industrial wastes to relieve the pollution of streams are varied in character. They consist generally in the removal of solid impurities in the form of sludge from the crude liquors by mechanical sedimentation processes, the removal of the finer organic materials both in suspension and in solution by some process of biochemical oxidation, and the economic disposal of the sludge solids by anaerobic fermentation or some mechanical means. In these biochemical oxidation processes for purification of the waste liquors, the phenomena of natural purification are invoked and the reactions stimulated. Environmental conditions are provided which facilitate biological activity in the work of breaking down the organic compounds and speeding up atmospheric reaeration for replenishment of the dissolved oxygen supply. The method of application of these principles is influenced largely by the nature of the waste to be handled, and for this purpose research studies are indispensable.

Much has already been accomplished and many forms of organic industrial wastes can now be treated economically and effectively, but a great deal of work still remains to be done as new industrial processes with their resulting waste products add to the complexities of the general problem of stream pollution.

A most encouraging development in the control of stream pollution in recent years has been the cooperation of industry with government in earnest endeavors to find practical solutions for industrial waste disposal problems. The replacement of mutual suspicion of motive by mutual understanding of purpose on the part of both industry and administrative authority has resulted in real advance and practical accomplishments. Industry can render a lasting beneficial service to both itself and to the welfare of the country at large by pursuing this policy of helpful cooperation in solving the varied problems of stream pollution.

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